Radiofrequency in arthroscopic shoulder surgery: a systematic review

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Background: Radiofrequency has seen an increase in use in orthopedics including cartilage lesion debridement in the hip and knee as well as many applications in arthroscopic shoulder surgery. The purpose of this systematic review is to evaluate the safety and usage of radiofrequency in the shoulder.

Methods: This systematic review was registered with PROSPERO (international registry) and followed the preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) guidelines. Embase and PubMed were searched using: “shoulder,” “rotator cuff,” “biceps,” “acromion” AND “monopolar,” “bipolar,” “ablation,” “coblation,” and “radiofrequency ablation.” The title and abstract review were performed independently. Any discrepancies were addressed through open discussion.

Results: A total of 63 studies were included. Radiofrequency is currently utilized in impingement syndrome, fracture fixation, instability, nerve injury, adhesive capsulitis, postoperative stiffness, and rotator cuff disease. Adverse events, namely superficial burns, are limited to case reports and case series, with higher-level evidence demonstrating safe use when used below the temperature threshold. Bipolar radiofrequency may decrease operative time and decrease the cost per case.

Discussion: Shoulder radiofrequency has a wide scope of application in various shoulder pathologies. Shoulder radiofrequency is safe; however, requires practitioners to be cognizant of the potential for thermal burn injuries. Bipolar radiofrequency may represent a more efficacious and economic treatment modality. Safety precautions have been executed by institutions to cut down patient complications from shoulder radiofrequency. Future research is required to determine what measures can be taken to further minimize the risk of thermal burns.

Key Words: Radiofrequency; Plasma energy; Arthroscopic shoulder surgery; Safety; Efficiency

INTRODUCTION

Radiofrequency (RF) refers to application of thermal energy to reorganize tissue on a molecular level and restore normal structure and function [1]. Traditional RF or electrocauterization refers to the use of thermal energy to treat surgical pathology by passing electrical current directly through tissue [1]. RF can be delivered through a monopolar or bipolar device [1-3]. Bipolar RF represents a safer alternative at lower temperatures, voltages, contact pressures, and contact times [1]. These devices create
high-energy free radicals that can break molecular bonds and excise soft tissue at relatively low temperatures (40°C–70°C) [2]. RF systems are widely used in arthroscopic orthopedic procedures for ablation, resection, and coagulation of soft tissues [3]. RF energy is not without its risks and does exhibit time-dependent effects that need to be considered by surgeons [4]. Next-generation RF devices utilize plasma energy fields to deliver thermal energy to minimize damage to the surrounding soft tissues [1,5].

The safety profile of RF has been studied in the knee in the context of low-grade cartilage lesions [2]. The safety of RF has also been well-studied in the hip for ablating soft tissues [6]. In the glenohumeral joint, RF was first studied in the context of instability but resulted in overtreatment [7], permanent tissue damage [7], and high failure rates necessitating capsular plication [8,9]. However, there are limited reports on the temperature profile and complications in shoulder joint RF.

In recent years, there have been many studies published regarding the use of RF energy in the surgical treatment of many shoulder pathologies. In the existing publications regarding RF use in the shoulder, the purpose of the equipment is to split and partially remove soft tissues [10-20]. However, the safety and complications of RF use to debride soft tissue have not been established. The purpose of this investigation is to conduct a systematic review of the currently available literature to evaluate the safety and complication profile of RF devices for use in the shoulder.

METHODS

General
This systematic review was registered in an international prospective register of systematic reviews (PROSPERO No. CRD42021288444). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Protocols (PRISMA-P) guidelines were followed.

Literature Search
The literature search was performed using Embase and PubMed with the keywords displayed in Table 1. The initial literature search revealed 1,531 studies. After removal of duplicate articles, title and abstract screening was performed on 1,374 studies. Of these, 537 studies did not pertain to the use of RF in arthroscopic shoulder surgery. Finally, the full-text of 837 studies was screened (Fig. 1).

Study Selection
Studies were selected according to the inclusion and exclusion criteria presented in Table 2. Of note, studies related to shoulder capsulorrhaphy usage were excluded, given the high complication rates of axillary nerve dysfunction, articular cartilage damage, and capsular necrosis [21]. Application of our inclusion and exclusion criteria resulted in a total of 63 studies.

Qualitative Synthesis
Due to a limited number of high-level clinical studies on the topic and heterogeneous reporting of data, the included studies were

Table 1. Search keywords used in the literature search

<table>
<thead>
<tr>
<th>Search term category</th>
<th>Keywords used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anatomic location</td>
<td>‘shoulder,’ ‘rotator cuff,’ ‘biceps,’ ‘acromion’</td>
</tr>
<tr>
<td>Radiofrequency modality</td>
<td>‘monopolar,’ ‘bipolar,’ ‘ablation,’ ‘coblation,’ ‘turbovac,’ and ‘radiofrequency ablation’</td>
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</tbody>
</table>
qualitatively synthesized. The included studies were grouped into those that contained data regarding the performance profile of RF and those that did not. The performance profile was defined as any mention of the temperature profile, safety profile and complication rate, or clinical outcomes. These studies were grouped accordingly and descriptively summarized in the tables.

**RESULTS**

**General**

Of our 59 included articles, 39 did not include RF performance in terms of temperature profile or complications. The remaining 20 studies did include at least one of these measures. The studies in this review that discuss RF for shoulder arthroscopic orthopedic procedures without data on performance profile do provide insight regarding the breadth of shoulder RF use and are summarized in Table 3 \[10,12-19,22-51\]. Table 3 revealed bipolar RF as the most commonly used modality. Of the 39 studies depicted in Table 3, only 17 (43.6%) specified the RF modality, all of which were bipolar. The remaining 22 studies (56.4%) were unspecified.

**Performance Profile**

Studies that disclosed the performance profile of RF usage in the shoulder were further analyzed. These studies were grouped by temperature profile (Table 4) \[3,20,52-62\] and complications (Table 5) \[21,63-68\]. Barker et al. \[55\] found the most crucial factor in subacromial temperature to be fluid irrigation temperature. For this reason, they recommended against the use of warmed irrigation fluid in RF. Davies et al. \[56\] also suggested that irrigation fluid be cooled before RF usage. In their case series of 30 patients, subacromial bursa temperature during RF with a monopolar device was assessed. Mean (27.8°C) and maximum (41.8°C) temperatures were observed well below the chondrocyte damage threshold temperature. The authors explained the isolated reading of 41.8°C to be due to blockage of the RF suction probe \[56\].

Good et al. \[58\] performed a cadaveric study regarding intraarticular temperatures during shoulder RF use. Intraarticular temperatures increased above 45°C in each trial. The highest peak temperatures were observed when the fluid flow rate was 0%, while the lowest peak temperatures were observed when the fluid flow rate was 100% \[58\]. No statistical differences in mean temperature were observed whether the device was immersed in fluid or in direct contact with tissue \[58\]. Zoric et al. \[57\] demonstrated three factors that were critical for maintaining safe intra-articular temperature: rate of flow, distance of device application, and duration of usage. This study also suggested that maximization of irrigation flow, shorter duration of device use, and adequate suction techniques further prevent temperature-related patient complications and injuries.

**Safety and Complications**

Overall, reports of postoperative complications following RF methods were lacking (Table 5). Our literature search revealed one prospective controlled trial, one case series, and five case reports that provided significant complication rates or commented on the safety profile. The small number of reported complications from RF usage within the literature was related to increased irrigation fluid temperature and was limited to case reports \[55\] and case series \[65\]. Four cases of second-degree burns were reported by Troxell et al. \[65\] due to a bipolar RF device being used in an unreported number of patients over 4 years. The authors \[65\] attributed these four cases to lack of outflow tubing. Since changing their practice, further burn cases have not occurred.

The most common adverse events of RF use are thermal inju-
Table 3. Studies included within this review article where RF device usage occurred without performance outcome disclosure by authors

<table>
<thead>
<tr>
<th>Study</th>
<th>Use</th>
<th>Study purpose</th>
<th>Device used</th>
<th>Radiofrequency mode</th>
<th>Amount of radiofrequency use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baumgarten et al. [22]</td>
<td>Acromioclavicular joint reconstruction</td>
<td>To propose a novel technique for the reconstruction of acromioclavicular joint</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Cvetanovich et al. [10]</td>
<td>Adhesive capsulitis</td>
<td>To report outcomes after 360° arthroscopic capsular release for glenohumeral adhesive capsulitis performed in the lateral decubitus position</td>
<td>Super Turbovac 90 (Arthrocare; Smith &amp; Nephew, Austin, TX, USA)</td>
<td>Coblation</td>
<td>Major</td>
</tr>
<tr>
<td>Cvetanovich et al. [14]</td>
<td>Adhesive capsulitis</td>
<td>Description of an arthroscopic 360° capsular release method</td>
<td>Super Turbovac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Major</td>
</tr>
<tr>
<td>Arce et al. [13]</td>
<td>Adhesive capsulitis</td>
<td>To detail an arthroscopic capsular release for primary frozen shoulder syndrome</td>
<td>VAPR III (DePuy Mitek, Raynham, MA, USA)</td>
<td>Bipolar</td>
<td>Major</td>
</tr>
<tr>
<td>Katthagen et al. [23]</td>
<td>Anterior instability</td>
<td>Presentation of a novel technique in open Latarjet procedure along with an arthroscopic Hills-Sachs remplissage</td>
<td>Super Turbovac 90 (Arthrocare)</td>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td>Ganokroj et al. [24]</td>
<td>Anterior instability</td>
<td>To propose a novel arthroscopic technique called the &quot;double row-double pulley&quot; in the restoration of a bony Bankart lesion</td>
<td>Super Turbovac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Lewington et al. [25]</td>
<td>Anterior shoulder instability</td>
<td>To present a method for shoulder instability using lateral decubitus arthroscopic Latarjet procedure</td>
<td>StarVac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Gomes et al. [26]</td>
<td>Anterior shoulder instability</td>
<td>To present a Marfan’s Syndrome patient with recurrent anterior shoulder dislocation due to hyperlaxity requiring arthroscopic treatment</td>
<td>Unspecified</td>
<td></td>
<td>Major</td>
</tr>
<tr>
<td>Saithna et al. [17]</td>
<td>Biceps pathology</td>
<td>Description of a novel technique to transilluminate the bicipital groove and identify long head biceps tendon</td>
<td>Unspecified</td>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td>Shih et al. [27]</td>
<td>Biceps pathology</td>
<td>Introduction of a novel technique for arthroscopic suprapectoral biceps tenodesis utilizing an all suture method</td>
<td>Unspecified</td>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td>Valenti et al. [19]</td>
<td>Biceps pathology</td>
<td>To present a novel technique for arthroscopic biceps tenodesis</td>
<td>VAPR Coolpulse 90 (DePuy Mitek)</td>
<td>Bipolar</td>
<td>Major</td>
</tr>
<tr>
<td>Daggett et al. [28]</td>
<td>Biceps pathology</td>
<td>To describe a novel arthroscopic technique for bicep tenodesis, the “loop lock” technique</td>
<td>Unspecified</td>
<td></td>
<td>Minor</td>
</tr>
<tr>
<td>Saithna et al. [29]</td>
<td>Biceps pathology</td>
<td>To present a novel method to identify the long head biceps tendon within the subacromial space</td>
<td>Unspecified</td>
<td></td>
<td>Major</td>
</tr>
<tr>
<td>Su et al. [18]</td>
<td>Biceps pathology</td>
<td>To introduce a novel technique utilizing a double knotless screw for tenodesis of the long head of the biceps</td>
<td>Unspecified</td>
<td></td>
<td>Minor</td>
</tr>
</tbody>
</table>

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Table 3. Continued

<table>
<thead>
<tr>
<th>Study</th>
<th>Use</th>
<th>Study purpose</th>
<th>Device used</th>
<th>Radiofrequency mode</th>
<th>Amount of radiofrequency use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armandil et al. [30]</td>
<td>Brachial plexopathy</td>
<td>To describe a recollection of obstetrical brachial plexus palsy released with arthroscopic technique</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Li et al. [31]</td>
<td>Coracoclavicular ligament repair</td>
<td>Description of a novel technique for coracoclavicular ligament repair arthroscopically</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Major</td>
</tr>
<tr>
<td>Yalizis et al. [32]</td>
<td>Impingement syndrome</td>
<td>To describe the acquisition of a panoramic view of the subacromial space arthroscopically</td>
<td>Unspecified device</td>
<td>Unspecified</td>
<td>Major</td>
</tr>
<tr>
<td>Pagán Conesa et al. [33]</td>
<td>Impingement syndrome</td>
<td>Presentation of intramuscular lipoma of supraspinatus muscle causing impingement syndrome treated arthroscopically</td>
<td>Unspecified device</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>O’Brien et al. [34]</td>
<td>Impingement syndrome</td>
<td>To introduce a novel technique of the “subdeltoid approach” for anterior shoulder arthroscopy</td>
<td>Unspecified “radiofrequency ablation device”</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Mellano et al. [35]</td>
<td>Impingement syndrome</td>
<td>To propose an optimized technique for arthroscopic acromioplasty</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Valenti et al. [36]</td>
<td>Impingement syndrome</td>
<td>To describe a novel technique in arthroscopic subscapularis assessment after removal of the coracoid process for shoulder impingement prophylaxis</td>
<td>VAPR (DePuy Mitek)</td>
<td>Bipolar</td>
<td>Minor</td>
</tr>
<tr>
<td>Hendrix et al. [37]</td>
<td>Other</td>
<td>To describe a novel arthroscopic technique for Pec Minor release to treat shoulder pain and dysfunction</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Theopold et al. [38]</td>
<td>Other</td>
<td>To evaluate the accuracy of arthroscopic placement versus conventional placement of coracoclavicular tunnels</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Scheibel et al. [39]</td>
<td>Other</td>
<td>To present cases of gracilis tendon transclavicular-transcoracoid loop technique via arthroscopic Tight-Rope</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Almazan et al. [40]</td>
<td>Other</td>
<td>To compare and detail the results of the indirect bursal technique with the direct superior approach (the arthroscopic trans-articular distal clavicle resection)</td>
<td>VAPR 2 Side Effect (DePuy Mitek)</td>
<td>Bipolar</td>
<td>Minor</td>
</tr>
<tr>
<td>Boileau et al. [41]</td>
<td>Posterior instability</td>
<td>To introduce data from a novel arthroscopic posterior bone block technique</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Parada et al. [15]</td>
<td>Posterior instability</td>
<td>Description of novel graft transfer technique during arthroscopic posterior glenoid reconstruction</td>
<td>Super TurbVac (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Rausch et al. [42]</td>
<td>Postoperative stiffness</td>
<td>To describe a novel arthroscopic method for restoration of shoulder mobility treatment of scapula neck fractures</td>
<td>Ambient Super TurboVac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Major</td>
</tr>
<tr>
<td>Bhatia et al. [43]</td>
<td>Proximal humerus fracture</td>
<td>Introduction of proximal humeral plate removal via arthroscopy</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
</tbody>
</table>

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</tr>
</thead>
<tbody>
<tr>
<td>Park et al. [44]</td>
<td>Rotator cuff disease</td>
<td>Introduction of a novel technique within arthroscopic rotator cuff repair</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Shon et al. [45]</td>
<td>Rotator cuff disease</td>
<td>To describe a novel tenodesis performed via an arthroscopic suture anchor technique</td>
<td>Bisector Arthro Wand (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Petri et al. [46]</td>
<td>Rotator cuff disease</td>
<td>To describe a novel technique for open reduction internal fixation for posterosuperior rotator cuff repair and latissimus dorsi transfer</td>
<td>Super TurboVac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Laskovski et al. [47]</td>
<td>Rotator cuff disease</td>
<td>To introduce a novel technique in arthroscopic augmentation of rotator cuff repair with an acellular human dermal allograft</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Cabarcas et al. [48]</td>
<td>Rotator cuff disease</td>
<td>To describe the surgical technique of a “double-row” arthroscopic subscapularis repair</td>
<td>Super TurboVac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Chernchujit et al. [49]</td>
<td>Rotator cuff disease</td>
<td>To present a novel arthroscopic technique for the management of high graded bursal sided rotator cuff tears</td>
<td>Super TurboVac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Boutsiadis et al. [16]</td>
<td>Rotator cuff disease</td>
<td>To propose a modification of superior capsular reconstruction with a long head bicep autograft</td>
<td>Super TurboVac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Minor</td>
</tr>
<tr>
<td>Warth et al. [50]</td>
<td>Sternoclavicular joint disease</td>
<td>To describe a novel technique for arthroscopic sternoclavicular joint resection</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Yamakado et al. [51]</td>
<td>Suprascapular nerve entrapment</td>
<td>To quantify the learning curve using the log-linear model for arthroscopic suprascapular nerve decompression</td>
<td>Unspecified</td>
<td>Unspecified</td>
<td>Minor</td>
</tr>
<tr>
<td>Thompson et al. [12]</td>
<td>Adhesive capsulitis</td>
<td>To propose a novel technique for performing an arthroscopic capsular release</td>
<td>DYONICS EFLEX (Arthrocare)</td>
<td>Monopolar</td>
<td>Major</td>
</tr>
</tbody>
</table>

DISCUSSION

In this systematic review of the literature, 63 studies demonstrated the safety and efficacy of RF devices within the shoulder. Of these, 25 studies explicitly studied the temperature profile, safety profile, or clinical outcomes. Though the temperature and safety profile were reasonably well described, functional or patient-reported outcomes after RF treatment were sparse [10,11,13-19, 22,23,25-27,29-33,35,39-45,49-51].

Our study demonstrated that the landscape of shoulder RF has changed significantly since it was originally studied in the context of shoulder instability [1,7,9]. Given the unanimous findings of poor outcomes in this setting, RF is largely used for debriding soft tissue (Table 3). Yasura et al. [70] demonstrated that bipolar...
Table 4. Included studies for which the temperature profile was the primary outcome with regards to radiofrequency usage in the shoulder

<table>
<thead>
<tr>
<th>Study</th>
<th>Radiofrequency device used</th>
<th>Radiofrequency mode</th>
<th>Study type</th>
<th>Level of evidence</th>
<th>Number of patients</th>
<th>Use</th>
<th>Purpose</th>
<th>Main outcome</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faruque et al. [52]</td>
<td>Stryker Endoscopy Radio Frequency Ablation System (SERFAS) or Super Turbovac 90 (Arthrocare)</td>
<td>Bipolar and Coblation</td>
<td>Randomized control trial</td>
<td>I</td>
<td>40</td>
<td>Rotator cuff repair</td>
<td>To compare intraarticular temperature profile in standard ablation versus plasma ablation RF devices for arthroscopic rotator cuff repair</td>
<td>Although 7 patients registered temperatures above 45°C, no significant differences in intraarticular temperature were found between standard and plasma RF devices (p = 0.433).</td>
<td>Plasma ablation radiofrequency may be equivalent to standard radiofrequency. Further study is needed to determine the safety profile of plasma radiofrequency.</td>
</tr>
<tr>
<td>Gereli et al. [53]</td>
<td>Super Turbovac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Prospective cohort study</td>
<td>II</td>
<td>41</td>
<td>Subacromial decompression</td>
<td>The measured maximum temperature between the group receiving irrigation fluid of 34 °C and the group receiving 24°C irrigation fluid was not statistically significantly different with a mean rise of 7.34°C ± 0.7°C with concurrent RF use.</td>
<td>Irrigation fluid temperature may not influence intraarticular temperature during shoulder surgery. New generation coblation devices may have a safe temperature profile.</td>
<td></td>
</tr>
<tr>
<td>Chivot et al. [54]</td>
<td>Ambient Super Turbovac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Prospective cohort study</td>
<td>II</td>
<td>22</td>
<td>Subacromial decompression/rotator cuff surgery</td>
<td>To determine the effect of surgery site, radiofrequency modality, and other surgical details on intraarticular temperature during arthroscopic shoulder surgery</td>
<td>Additional portal sites reduced the temperature elevation by 3.8°C (p &lt; 0.05) when concurrent radiofrequency was used. Arthropump pressure plays a significant role in the intraarticular temperature as well (p &lt; 0.05). No significant difference was found regarding radiofrequency modality choice.</td>
<td>It is important to be cognizant of the variables that can affect intraarticular temperature during arthroscopic shoulder surgery. Radiofrequency modality may or may not be as important as other factors.</td>
</tr>
</tbody>
</table>

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<th>Number of patients</th>
<th>Use</th>
<th>Purpose</th>
<th>Main outcome</th>
<th>Conclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Huynh et al. [3]</td>
<td>Super Turbovac 90 (Arthrocare) and VAPR Mitek (DePuy Mitek, Raynham, MA, USA)</td>
<td>Coblation</td>
<td>Prospective controlled trial</td>
<td>II</td>
<td>13</td>
<td>Subacromial decompression</td>
<td>To investigate the temperature profile during arthroscopy within the subacromial space</td>
<td>No difference in temperature profile was demonstrated between VAPR and coblation within the first 40 seconds ($p &gt; 0.05$). After 40 seconds, coblation temperatures were higher than VAPR ($p &lt; 0.05$). All trials displayed temperatures below the chondrocyte threshold damage of 45°C.</td>
<td>There is minimal concern for temperature violation with both VAPR and coblation.</td>
</tr>
<tr>
<td>Barker et al. [55]</td>
<td>Super Turbovac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Case series</td>
<td>IV</td>
<td>15</td>
<td>Subacromial decompression</td>
<td>To investigate if the bipolar RF ablation wand causes excess heating</td>
<td>The mean peak temperature was 32.0°C in the subacromial bursa and 71.6°C in the outflow fluid during arthroscopic subacromial decompression. Baseline temperature of irrigation fluid most influenced bursal temperature</td>
<td>Bipolar RF can be safely used below the temperature threshold in the shoulder.</td>
</tr>
<tr>
<td>Davies et al. [56]</td>
<td>Ablator-S (Arthrocare)</td>
<td>Monopolar</td>
<td>Case series</td>
<td>IV</td>
<td>30</td>
<td>Impingement syndrome</td>
<td>To assess subacromial space temperatures during RF ablation of subacromial bursa</td>
<td>Both the mean and maximum temperatures reached in 30 case series patients were below the experimental thresholds for chondrocyte damage.</td>
<td>Radiofrequency can be used safely in the shoulder below the temperature limit.</td>
</tr>
<tr>
<td>Study</td>
<td>Radiofrequency device used</td>
<td>Radiofrequency mode</td>
<td>Study type</td>
<td>Level of evidence</td>
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<td>Use</td>
<td>Purpose</td>
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<td>Zoric et al. [57]</td>
<td>Super Turbovac (Arthrocare)</td>
<td>Coblation</td>
<td>Cadaveric study (10 cadavers)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>To investigate factors that impact joint temperature profiles with RF usage</td>
<td>Three factors are crucial in influencing joint capsule temperature: application duration, application distance, and flow rate, with the flow rate being the most important factor.</td>
<td>Maintaining appropriate joint temperature during shoulder radiofrequency treatment is important. These factors better enable clinicians to do so.</td>
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<tr>
<td>Good et al. [58]</td>
<td>VAPR3 (DePuy Mitek)</td>
<td>Bipolar</td>
<td>Cadaveric study (30 cadavers)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>To assess glenohumeral fluid temperature during shoulder arthroscopy and the effect RF energy has upon it</td>
<td>In this cadaveric study using VAPR3, joint temperatures rose above 45°C in all trials. A flow rate of 100% had reduced temperatures compared to a flow rate of 0%.</td>
<td>Bipolar radiofrequency has the potential to raise the intraarticular temperature, which can be detrimental to chondrocyte viability. Clinicians must keep this in mind while pursuing radiofrequency treatment in the shoulder.</td>
</tr>
<tr>
<td>Edwards et al. [59]</td>
<td>ArthroCare System 2000 (Arthrocare) and Vulcan EAS</td>
<td>Monopolar</td>
<td>Animal study</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>To compare and contrast cartilage matrix temperatures between the monopolar and bipolar RF energy devices</td>
<td>Monopolar RF devices were associated with lower temperatures and at greater depths within the cartilage</td>
<td>Monopolar radiofrequency can be safely used without violating the temperature limit of the shoulder.</td>
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<table>
<thead>
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<tbody>
<tr>
<td>Valet et al. [60]</td>
<td>Super Turbo Vac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Basic science study</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>To determine an optimal technique for prevention of damaging suture material in RF tissue ablation</td>
<td>High-strength ultra-high molecular weight polyethylene sutures were less sensitive to RF treatment than polyester sutures. By maintaining the distance between the probe and suture, damage can be reduced to sutures.</td>
<td>Suture choice can affect the safety of radiofrequency treatment in the shoulder.</td>
</tr>
<tr>
<td>Shah et al. [61]</td>
<td>Orthopedic Procedure Electrosurgical System (Arthrex, Naples, FL, USA)</td>
<td>Monopolar</td>
<td>Basic science study</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>To evaluate different sutures and the effect RF energy exerts on their mechanical properties</td>
<td>This study demonstrates that exposure to electrocautery damages and weakens sutures.</td>
<td>Radiofrequency has the potential to affect the integrity of all sutures tested and should be used with care around sutures.</td>
</tr>
<tr>
<td>Lemos et al. [20]</td>
<td>Ambient Super Turbo Vac 90 (Arthrocare)</td>
<td>Coblation</td>
<td>Cadaveric study (17 specimens)</td>
<td>NA</td>
<td>NA</td>
<td>Biceps tenodesis or tenotomy</td>
<td>To describe a novel technique of outlet biceps tenodesis</td>
<td>In comparison to traditional tenotomy on cadavers, biomechanical testing showed favorable pullout force results from this technique.</td>
<td>Radiofrequency use was used in a novel biceps tenodesis technique that did not result in any adverse effects.</td>
</tr>
<tr>
<td>Ficklscherer et al. [62]</td>
<td>OPES CoolCut (Arthrex)</td>
<td>Bipolar</td>
<td>Animal study (189 rats undergoing rotator cuff repair)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>To investigate foot-print preparations in rotator cuff repair along with their histological and biomechanical outcomes</td>
<td>RF in comparison to spongialisation of the footprint was associated with poorer biomechanical and histological outcomes.</td>
<td>RF cannot be advised in place of spongialisation for rotator cuff repair.</td>
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</table>

RF: Radiofrequency. NA, not applicable.
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<tr>
<td>Nho et al. [21]</td>
<td>VAPR Mitek (DePuy Mitek, Raynham, MA) and OraTec Vulcan EAS (OraTec, Manassas, VA, USA)</td>
<td>Bipolar</td>
<td>Prospective randomized clinical trial</td>
<td>I</td>
<td>50</td>
<td>Varied</td>
<td>To investigate if RF energy devices originally from coagulation and soft tissue ablation cause thermal injury to the bone</td>
<td>With MRI, no cases of osteonecrosis or bone edema occurred with monopolar or bipolar RF devices.</td>
<td>There may not be any injury or insult that is detectable on imaging studies after utilization of radiofrequency in the shoulder.</td>
</tr>
<tr>
<td>Jerosch et al. [63]</td>
<td>VAPR (DePuy Mitek)</td>
<td>Bipolar</td>
<td>Case report</td>
<td>IV</td>
<td>1</td>
<td>Capsular release</td>
<td>To present a case of chondrolysis post arthroscopic capsular release for adhesive capsulitis with a bipolar VAPR RF energy probe</td>
<td>Glenohumeral chondrolysis occurred after treatment with the bipolar VAPR RF probe, although rare. A surface replacement was required.</td>
<td>Chondrolysis can occur as a complication of bipolar radiofrequency in the shoulder.</td>
</tr>
<tr>
<td>Bonsell et al. [64]</td>
<td>Unspecified device</td>
<td>Bipolar</td>
<td>Case report</td>
<td>IV</td>
<td>1</td>
<td>Subacromial decompression</td>
<td>To present a case of deltoid detachment that occurred during arthroscopic subacromial decompression</td>
<td>Overaggressive use of the bipolar RF was attributed to deltoid detachment by the authors.</td>
<td>Bipolar radiofrequency use is not without its risks. The practicing shoulder surgeon needs to be aware of these risks.</td>
</tr>
<tr>
<td>Troxell et al. [65]</td>
<td>SuperTurbo Vac 90 (Arthrocare; Smith &amp; Nephew, Austin, TX, USA)</td>
<td>Coblation</td>
<td>Case series</td>
<td>IV</td>
<td>4</td>
<td>Subacromial decompression</td>
<td>To present reports of shoulder arthroscopy bipolar RF-induced burn injuries within patients</td>
<td>Four patients over 4 years suffered second-degree burns after irrigation fluid from outflow tubing contacted the patients.</td>
<td>Orthopedic surgeons need to be cognization of burn risk during radiofrequency of the shoulder.</td>
</tr>
<tr>
<td>Chahar et al. [66]</td>
<td>VAPR (DePuy Mitek)</td>
<td>Bipolar</td>
<td>Case report</td>
<td>IV</td>
<td>1</td>
<td>Rotator cuff repair</td>
<td>To present a dermal burn case that occurred after a radiofrequency procedure</td>
<td>The suction device was removed leading intraarticular fluid temperature to increase. Dermal burns occurred as a consequence of RF subacromial decompression.</td>
<td>Practitioners need to be aware of the complication of thermal burns.</td>
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RF resulted in significantly less chondrocyte death than unipolar RF in the knee. The results of our systematic review seem to be in concordance with this and demonstrate a general trend toward the use of bipolar RF in recent years. Though a few studies in our literature review demonstrate adverse thermal effect profiles, these are limited to case reports [65-67], case series, and cadaveric studies [58]. Shoulder joint temperature increases with the use of RF technologies [3,55,58]. The flow of irrigation fluid [55,57,58], length of application [55,57], device used [3], and proximity of the thermometer to the RF wand [57,58] all impact the temperature profile.

The incidence of RF complications was appropriately reported [21,63-68,71] and generally comprised superficial burns related to fluid irrigation temperature [65-68]. All of the Level III or higher studies reporting temperature profile demonstrate a favorable profile (Table 5). This is in concordance with the literature on RF use in the knee [1,5] and hip [6]. Maintenance of inflow and outflow circulation, avoidance of plugged arthroscopic fluid outflow, avoidance of excess use of coagulation mode [54], and monitoring overheating of the tubing can be performed to reduce burn complications with RF in the shoulder. It is well known that cartilage is more heat-sensitive than other tissues in the human body, and this must be considered when treating cartilage lesions [1].

It is important to consider economic efficiency when determining the RF modality of choice. Efficiency and cost between monopolar RF and bipolar RF in 40 arthroscopic subacromial decompression patients were investigated by Diab et al. [72]. The mean operative time in the bipolar group was 13 minutes (5–25 minutes), while it was 21 minutes (10–35 minutes) for the monopolar RF device group. Bipolar RF decreased the average procedure time by 8 minutes (p < 0.0001), while simultaneously decreasing cost by 83 British Pounds (111 European Euros) per case (p < 0.003) in comparison to monopolar RF [72]. Based on these results, the authors recommended bipolar RF when clinical judgment deems it appropriate.

This systematic review is not without its limitations. As a systematic review of level I–level IV evidence, the findings are limited to level IV. Due to heterogeneous data reporting, this is a comprehensive summary of all studies delineating the use of RF in the shoulder as defined by the inclusion and exclusion criteria. However, many of the studies included were limited by unspecified use of RF. Further, our study is unable to comment on the clinical outcomes of RF based on the inclusion criteria regarding temperature profile and safety/complications of shoulder RF. The results pertaining to safety and complication are based on a limited subset of select articles. Thus, the findings of this study may
be limited by selection bias.

Shoulder RF has a wide scope of application in various shoulder pathologies. Although shoulder RF is safe, it requires practitioners to be cognizant of the potential for thermal burn injuries. Protocols regarding irrigation fluid temperature and outflow rates should be set by individual institutions to further reduce minor patient complications of shoulder RF. Future research is required to determine measures to minimize further the risk of thermal burn injuries.

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